Emitter clogging when using water from a tributary of the Bogota River in Colombia

Taponamiento de goteros utilizando agua de un afluente del río Bogotá en Colombia

Johana Almario-Narváez[1], Javier Enrique Vélez-Sánchez[1], and María Jaqueline Molina-Ochoa[1]

ABSTRACT

An experiment was conducted to study the behavior of three types of emitters used in Colombia under real-work conditions using water from the Neusa River, a tributary of the Bogota River. The emitters included: an in-line turbulent-flow emitter (E1), an integrated turbulent-flow emitter (E2), and an integrated self-regulated turbulent-flow emitter (E3). The operation and quality of the emitters were evaluated taking into account the flow decrease trend over time (RF), the flow reduction percentage of the emitters (qr), the coefficient of variation (*Cv*), the Christiansen uniformity coefficient (CU), and the emission uniformity (EU). The results indicated that the water quality in general affected the performance of the emitters over time, depending on the characteristics and properties of the emitters. The EU and CU decreased in the three emitter types as the experiment progressed and the *Cv* and qr increased. The E2 emitter showed a lower *Cv* and qr and a higher CU and EU than the E1 and E3 emitters.

Key words: micro irrigation, emitter, water quality.

RESUMEN

Se realizó un experimento para estudiar el comportamiento de tres tipos de emisores utilizados en Colombia en condiciones de operación real, tomando como fuente de agua el río Neusa afluente del río Bogotá. Los emisores utilizados fueron: gotero en línea de flujo turbulento (E1), gotero integrado de flujo turbulento (E2) y gotero integrado de flujo turbulento autorregulado (E3). El funcionamiento y calidad de los emisores fue evaluado teniendo en cuenta: la tendencia de diminución del caudal en el tiempo (RF), la reducción de caudal del emisor en porcentaje (qr), el coeficiente de variación (*Cv*), el coeficiente de uniformidad de Christiansen (CU) y la uniformidad de emisión (EU). Los resultados muestran como la calidad del agua afectó el desempeño del gotero a través del tiempo, dependiendo de las características y propiedades del emisor. La EU y el CU en los tres tipos de emisores disminuyó a medida que avanzó la experimentación y el *Cv* y qr, aumentaron. El emisor tipo E2, mostró menores *Cv* y qr y un mayor CU, EU que los emisores tipo E1 y E3, respectivamente.

Palabras clave: micro-irrigación, emisor, calidad.

Introduction

Due to the scarcity of water and advances in plastics, micro irrigation using driplines has rapidly increased throughout the world (Vélez *et al*., 2011) because it optimizes the use of water and improve the developmental conditions of plants through a highly efficient supply of water (Vélez and Álvarez, 2012). The main problems with microirrigation is the obstruction of emitters due to reduced passages in the lines (Li *et al*., 2010; Vélez *et al.,* 2013), water quality in general (Zhang *et al*., 2007; Liu and Huang, 2009), chemical reactions from the use of fertilizers, lateral positioning of emitters (Ravina *et al*., 1997; Yiting *et al*., 2014), fabrication material and environmental conditions (Vélez *et al*., 2013).

Clogging can be classified as follows: physical, caused by materials suspended in the water; chemical, caused by the formation of precipitates of calcium, iron, magnesium, phosphates, and sulfates; and biological, caused by the presence of algae, microorganisms and organic material (Capra and Scicolone, 2007; Puig-Bargues *et al*., 2010; Li *et al*., 2013, 2015). De Kreij *et al*. (2003) found that laminar and vortex emitters experienced more obstruction than turbulent flow ones. In the majority of cases, high-flow emitters have less obstruction than low-flow ones because of the size of the lines.

Obstructions in emitters reduce the uniformity of water distribution, which causes a reduction in production and irreversible damage in plants that is normally detected when it is too late (Vélez *et al*., 2013; Puig-Bargues *et al*., 2010).

The Neusa River, a tributary of the Bogota River, is used for irrigation. Problems related to water resources and the techniques developed to increase the efficient use of these resources depend on the quality of the irrigation equipment, specifically the emitters and driplines (Vélez *et al*., 2013).

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[1] Department of Civil Engineering and Agricultural Engineering, Faculty of Engineering, Universidad Nacional de Colombia. Bogota (Colombia). jevelezs@unal.edu.co

This study aimed to analyze and evaluate the effect of the water used on the flow, distribution uniformity, clogging and washing effect issuers with clean water and a solution of phosphoric acid of three emitter types used in the commercial cultivation of roses for a period of one year.

Materials and methods

This study was carried out from March of 2011 to April of 2012 on the Guaticha Farm in the municipality of Zipaquira, Cundinamarca, at 5º5.48’ N and 73º57.24’ W, at an altitude of 2,600 m a.s.l., in a commercial crop of mini-roses (*Rosa* spp.) Cherry variety, grown for export and planted in a greenhouse in 2006 in an approximate area of 0.5 ha.

Following the general classification of Koeppen and Thornthwaite, (IGAC, 2000), the climate consisted of a mean temperature of 14ºC with average lows of 5.6ºC and highs of 18ºC; a cool, moist area that is characteristic of zones with moderate precipitation between 500 and 1,000 mm year^{-1}, with two rainy periods and two dry periods.

Plastic covers and greenhouses were used to modify the climatic conditions of the crops (IGAC, 2000).

The effective annual and monthly precipitation was 637.9 mm, calculated by the method from the US Soil Conservation Service using CropWat 8 Beta from the Department of Natural and Environmental Resources (FAO, 2013).

The annual potential evapotranspiration (*ETo*), as determined with the Thornthwaite method and data from the Zipaquira weather station, was 665.3 mm, with a monthly mean of 54.61 mm and maximum of 60.40 mm in May, equal to 2.01 mm d^{-1}. There was a water balance of 444.70 mm year^{-1}, a mean monthly relative humidity of 72% and 145 sunlight hours per month. The amount of irrigation water applied to the crop during the experiment (ETc) was calculated with the Penman-Monteith equation (Allen *et al*., 1998; Arenas *et al*., 2012; Vélez *et al*., 2007), taking into account the crop coefficient (Kc).

The soils came from the quaternary deposits with fluvial and lacustrine origins. The terrain was flat and the parental marital was mantles of volcanic ash on hydrogen clastic deposits, with low to moderate evolution and moderately fine texture (silt clay loam), deep and well-drained with iron and moderately developed sub-angular block structures, a high cationic exchange capacity, low base saturation, medium to low calcium contents and low contents of magnesium, potassium, and phosphorous, and moderate fertility (IGAC, 2000).

Water from the Neusa River, a tributary of the Bogota River, was used for the experiment. The characteristics and properties of the irrigation water and the clogging risk was measured in three samples can be seen in Tab. 1 (Nakayama and Bucks, 1991). During the study, the conditions of the

TABLE 1. Initial analysis (March 2015) and interpretation of the water quality from a tributary of the Bogota River. Classification of irrigation water (US Salinity Laboratory) (Pizarro, 1996).

Analysis	Units (mg L^{-1})	Units (meq L^{-1})	Probability of obstruction	Permissible toxicity concentration limit
pH	7.10		Low	
EC (dS m^{-1})	0.64			No restriction
Cations				
Ca^{2+}	3.01	0.15	Low	2- 6 meq L^{-1}
Mg^{2+}	3.28	0.27		0.49-2.06 meq L^{-1}
K^{+}	2.74	0.07		< 0.26 meq L^{-1}
Na^{+}	5.29	0.23		< 1.79 meq L^{-1}
Fe^{+}	3.44	0.12	High	< 5 mg L^{-1}
Anions				
SO_4^{2-}	34.95	0.36	Low	
Cl^{-}	26.59	0.75	Low	
CO_3^{2-}	NA		Low	
HCO_3^{-}	63.45	1.04		Severe restriction in the spray irrigation
Hardness		20.72	Soft water	
SAR (sodium absorption ratio)		0.50		No restriction
RSC (residual sodium carbonate)		0.82		Class I, Water good for irrigation*

TABLE 2. Analysis and interpretation of the evolution water quality from a tributary of the Bogota River.

Parameters	July 1, 2011	October 15, 2011	January 30, 2012	Probability of obstruction	Permissible toxicity concentration limit
pH	7.10	7.82	6.49	Low	
EC (dS m^{-1})	0.64	0.63	0.60		No restriction
Fe^+ (mg L^{-1})	3.44	5.0	5.0	High	< 5 mg L^{-1}
Hardness (meq L^{-1})	21.0	22.0	30.0	Soft water	

irrigation water was measured four times in three samples and the quality was stable although with high risk of clogging by iron (Tab. 2).

The irrigation system used a centrifuge pump that supplied 45 $m^3 h^{-1}$ at 0.55 MPa and a filtration unit that filtered 45 $m^3 h^{-1}$ with 22.71 m^3 h^{-1} filters (two gravel filters and two mesh filters, 83 µm), along with lateral and mainline pvc pipes of 110, 90 and 63 mm diameters, Venturi fertilizer and safety and control values.

The three-emitter types had a turbulent flow of 2 L h^{-1} and included the following: turboline (E1), interline (E2), and interline PC (E3), made in Colombia by Agrifim of Colombia S.A. The tubes had polyethylene emitters with nominal diameters of 12, 16, and 18 mm, respectively.

The emitters were characterized in the irrigation laboratory of the Faculty of Engineering of the Universidad Nacional de Colombia to know the initial operation condition, with 26 emitters for each type (78 in total). The samples were randomly selected for the flow uniformity test. Each test had five replications in order to carry out the corresponding statistical analyses for the mean flow (Qm), coefficient of variation (*Cv*), emitter exponent (x), dimensions of the openings of the tubes and category (data not shown), taking into account the ISO 9260 standard (ISO, 1991).

Also, for each line type, three emitters were selected and transversely cut for a visual comparison, looking for the presence of defects such as grooves, cracks, or burrs, which can affect proper functioning. A 0.02 mm precision dial gauge was used to measure the openings in the passages in three lines for each type: height, width, internal diameter, external diameter, number of entrance filter teeth for the emitter, size of the teeth openings, height of the cap and thickness and diameter of the diaphragm.

This experiment was carried out from March of 2011 to April of 2012. The tasks were conducted following the management established for the production of flowers in a commercial crop. The water and fertilizer applications were done daily starting at the beginning of the experiment in accordance with the water requirements calculated during the total effective irrigation times of 101, 81, and 109 h for the E1, E2, and E3 emitters, respectively, for an application of 1.000 L per week per bed.

The experiment design used a total of 18 irrigation lines in nine rose beds, six lines for each line type of emitters (turboline-E1, interline-E2 and interline PC-E3), independently controlled by a valve. Each bed had a length of 30 m and a width of 0.90 m, with two driplines with 2 L h^{-1} emitters spaced 0.30 m apart.

Four emitters were selected from each of the six lines used for each type: the first one at the beginning of the bed (EX1), the second one at 10 m (EX2), the third at 20 m (EX3), and the fourth at 30 m or the end of the bed (EX4), for a total of 24 per line type, to determine the operating conditions along the line, which were periodically measures.

Once the experiment was finished, the irrigation lines were taken to the laboratory where they were flushed with clean water for 3 min at 0.14 MPa and the pressure washing process was started, subjecting the unobstructed lines to pressures of 0.17, 0.21, and 0.31 MPa for 3 min for each pressure amount and subjecting the obstructed lines to a pressure of 0.31 MPa in order to observe the uncapped emitters in accordance with the methodology used by (Liu and Huang, 2009), regular pressures for process gradual washing. Subsequently, all the emitters were placed in a solution of 5 g L^{-1} of phosphoric acid (H_3PO_4) normality (45) at a concentration of 83% for 5 d, then they were flushed for 3 min at a pressure of 0.21 MPa in order to observe the effect of cleaning on each line type (Netafim, 2012).

Criteria for evaluating the clogging of the emitters

The criteria used for evaluating the clogging of the emitters included the mean flow (qm), the flow decrease trend over time (RF), flow reduction percentage (qr), coefficient of variation (Cv), emission uniformity (EU), and Christiansen Uniformity Coefficient (CU) (Liu and Huang, 2009).

The flow decrease trend over time (RF) was calculated with Eq. 1:

$$RF = qm/qi \tag{1}$$

where qm and qi, are the mean and initial flow of each emitter type in L h^{-1}.

Flow reduction percentage (qr) was calculated with Eq. 2:

$$qr = \{(qi-qm)/qi\} = 100\ (1-RF) \tag{2}$$

Coefficient of variation (Cv) was calculated with Eq. 3:

$$Cv = 100\ SD/qm \tag{3}$$

where SD is the standard deviation and qm is the mean flow in L h^{-1}

Emission uniformity (EU) was calculated with methodology of Meriam and Keller (1978) in Eq. 4:

$$EU = 100\ (qm_{1/4}/qm) \tag{4}$$

Where qm $_{¼}$ is the lowest mean flow from the emitters in the last quarter of the lines and qm is the mean flow in L h^{-1}.

Christiansen uniformity coefficient (CU) was calculated with Eq. 5:

$$CU = \{1- (\Sigma qi-qm)/Nqm\} \tag{5}$$

where qi is the mean flow of emitter i, qm is the mean flow in L h^{-1}, and N is the total number of measured emitters.

At the beginning of the experiment with the purpose of knowing the pressure at the end of each line irrigation was measured with a pressure gauge and calculated with the equation Hazen Williams may be expresses as Hf, see Eq. 6 (Boswell, 1990).

$$Hf = 10{,}67\ (Q/C)^{1.852}\ L/(D^{4.871}) \tag{6}$$

where Hf, is the friction loss (m); Q, is the flow rate (m^{3}s^{-1}); C, is the friction coefficient for plastic pipes (C=150); L, is the pipe length (m); D, is the internal diameter (m).

The results were analyzed with the coefficient of variation, the standard error, and the univariate analysis of variance following a Tukey test with $P \leq 0.05$, using SAS/STAT® (SAS, 2008).

Results and discussion

The emitter flow decreased as the distance from the lateral branch increased due to the decreased pressure caused by losses due to friction, which were 0.015, 0.003 and 0.001 MPa for emitters E1, E2 and E3, respectively, measured at the end of each drip line with a pressure gauge, coinciding, although slightly lower than those calculated with the theoretically but with high correlation between the absolute values which were 0.016, 0.004 and 0.001 MPa for emitters E1, E2 and E3, respectively calculated by Hazen Williams equation, taking into account the parameters in Tab. 3.

TABLE 3. Parameters for calculating the losses due to friction in the irrigation lines using different emitters types according to Hazen Williams equation with water from a tributary of the Bogota River.

Parameters	Turboline	Interline	Interline PC
Line length (m)	30.00	30.00	30.00
Distance between emitters (m)	0.30	0.30	0.30
Emitter flow (L h^{-1})	2.00	2.00	2.00
Line diameter (mm)	12.00	16.00	18.00
Internal diameter measured of line (mm)	9.80	13.30	13.90
Christiansen coefficient (Kc)	0.35	0.35	0.35
Loss due to friction calculated (MPa)	0.016	0.004	0.001
Loss due to friction measured (MPa)	0.016	0.003	0.001

At the beginning of the experiment, the differences in the flow between the emitters of the first and last quarter of the driplines were 13.72, 2.71 and 2.45% for emitters E1, E2, and E3, respectively. The difference was greater in emitter E1 due to the smaller internal diameter in the irrigation line (9.8 mm); however, it was found to be in the permissible range of losses due to friction for this type of dripline (Boswell, 1990). E3 had the lowest difference due to be larger diameter, or being self-regulated.

As the experiment progressed, due to the effect of the low pressure at the end of the driplines, there was sedimentation of particles and fine material that led to an increase in the partial clogging of the emitters at the end of the lines due a low pressure; results that agree with those found by (Liu and Huang, 2009). Figure 1A shows the tendency seen in the E1 emitters, 12 mm, for a decrease in flow over time, depending on the position of the emitters on the irrigation lines. The E14 emitters (located at 30 m or the end of the beds) had a greater decrease between the start and end of the tests, with significant differences ($P \leq 0.05$) with E11 (located at the beginning of the beds), and always had a lower flow than the E12 and E13 emitters (located at 10 an

20 m from the beginning of the beds, respectively) with significant differences ($P\leq0.05$), except at days 17, 22, 45 and 207 with E13.

The interline (E24) and interline PC emitters (E34), during most of the experiment, had a lower flow at E21, E22 and E23, and at E31, E32 and E33, respectively, with significant differences ($P\leq0.05$) between E24 and E23 at days 126 and 295 and between E34 and E31 on day 295, due the position of the emitter in line (Figs. 1B and 1C).

At the end of emitters E14, E24 and E34, the flow decreased starting at day 135, with slight recoveries in E34 between day 172 and 207, possibly because of sporadic cleaning of the diaphragm (Fig. 1).

The univariate analysis of variance determined the susceptibility to clogging in accordance with the height of the emitter passages, which is the limiting dimension that affects the flow of particles (Velez *et al*., 2013). The emitters had a passage height of between 0.70 and 1.50 mm, which theoretically means that they are slightly susceptible to clogging, and had significant differences according to the Tukey test ($P\leq0.05$), E2 = 0.7467 mm (a), E1= 0.9733 mm (b) and E3 = 1.0533 mm (c).

The flow reduction in the first days oscillated until day 207, when there was a smaller reduction in emitter E2 with significant differences with E3, which was maintained until day 295. The same occurred with E1; however, at the end of the experiment, the maximum flow reduction corresponded to 24.80, 30.70 and 34.66% for E2, E3 and E1, respectively (Fig. 2A).

The coefficient of variation (Cv) increased as the experiment progressed, similar to the results found by (Liu and Huang, 2009) and was more than double that in E2 (14.97%), E3 (32.15%) and E1 (32.53%), respectively, at the end of the experiment. Figure 2B shows that, starting on day 1, there were significant differences according to the Tukey test ($P\leq0.05$), *between emitters E1 and the emitters E2 and E3. On day 108 there* were differences between E1 and E3. On day 207 between the emitters E3 and the emitters E1 and E2, and on day 360 between E2 and E3. At the end of the experiment, there was no significant difference among the emitters.

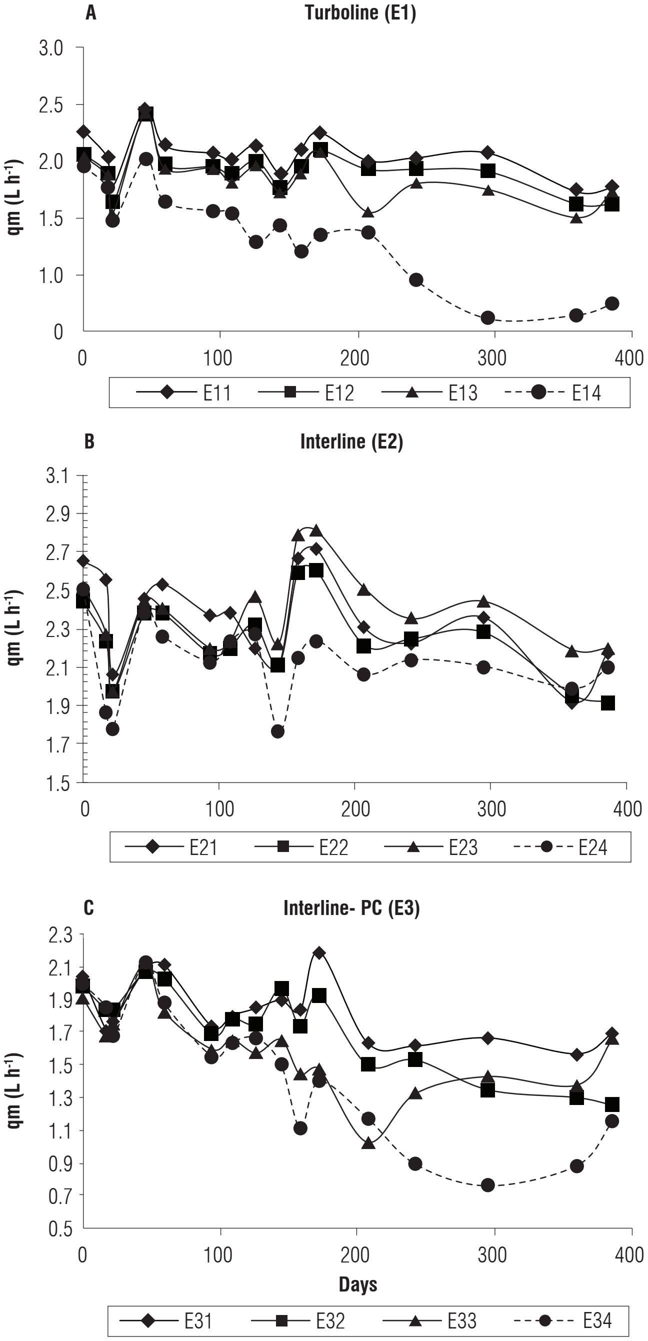

FIGURE 1. Flow (qm) of three emitter types and emitter position in the irrigation driplines using water from a tributary of the Bogota River. Emitter types: A, turboline-E1; B, interline-E2; interline PC-E3. Localization of emitter: Ex1, 0-10 m; Ex2, 10-20 m; Ex3, 20-30 m; Ex4, 30-40 m.

Figure 2C shows that the CU decreased during the experiment. Starting at day 126, the decrease was higher in emitters E1 and E3. At the end, the lower values were 72.14, 72.28 and 89.34% for E1, E3 and E2, respectively, with significant differences between E2 and E3 from day 242 and with E1 from day 295.

The same behavior occurred for the emission uniformity (EU) in E3, which reached a minimum of 26.25% on day 360, E1 (38.45%) on day 295 and E2 (78.68%) on day 386. Throughout the entire experiment, E2 had a higher EU than

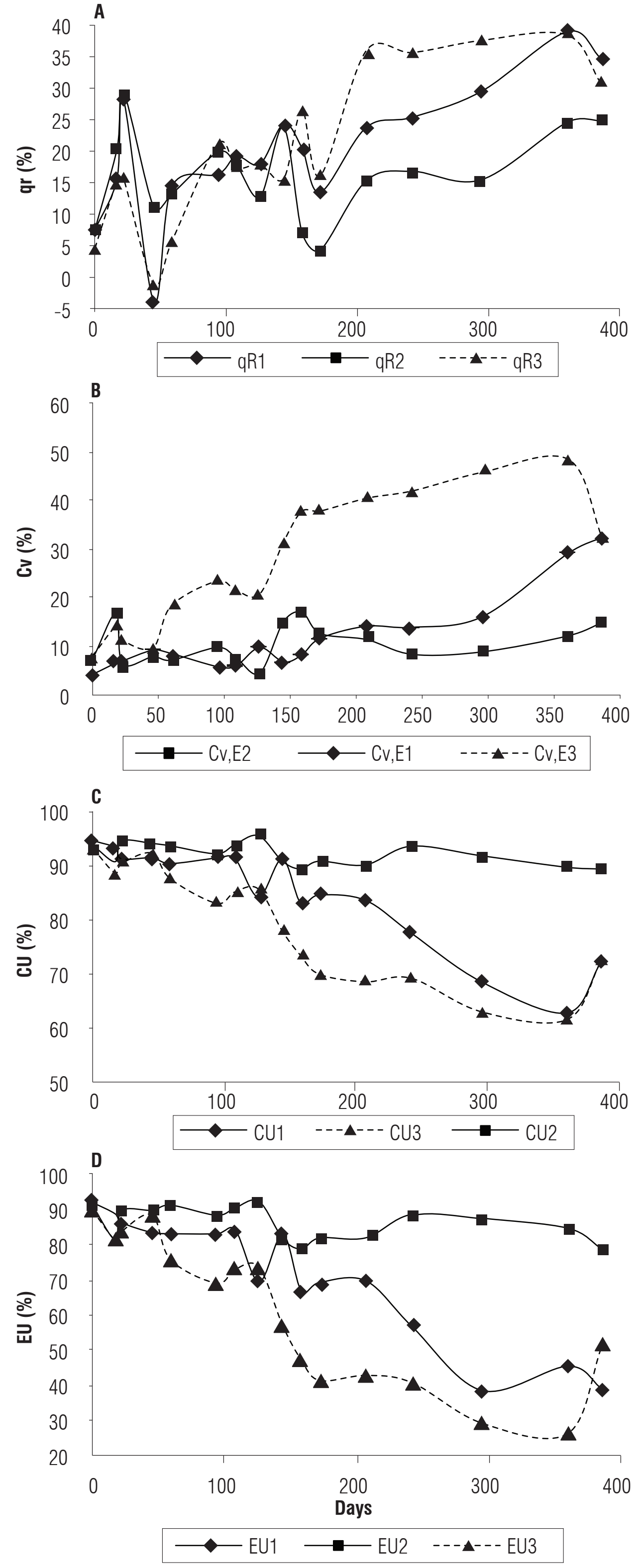

FIGURE 2. Flow reduction percentage-qr (A), coefficient of variation-Cv (B), coefficient of uniformity-CU (C) and emission uniformity-EU (D) of three emitter types and emitter position in the irrigation line using water from a tributary of the Bogota River. Emitter types: E1, turboline; E2, interline; E3, interline PC. Localization of emitter: X1, 0-10 m; X2, 10-20 m; X3, 20-30 m; X4, 30-40 m.

E1 and E3, with significant differences ($P \leq 0.05$) on day 360 (Fig. 2D). The reason for the quick decrease for EU1 and EU3 was the flow reduction high percentage for E1 and E3.

The pressure-cleaning process in the laboratory with water and four cycles resulted in a flow recovery of 3.06% in E1. In E2, the effect was the opposite, decreasing the flow by 0.51%, possibly due to the loosening of material or sediment in the tubes and emitters that further obstructed the driplines. However, in E3, the cleaning had no effect and the flow remained the same.

The final pressure-cleaning, after soaking the emitters in a solution of 5 g L^{-1} phosphoric acid for 5 d, resulted in a mean flow recovery in the emitters equal to 10.52, 8.33 and 5.16% for E3, E2 and E1, respectively.

Although there was flow recovery in the three-dripline types, it is worth noting that this recovery would not be easy with lines in the field because the plants, soil and environment could be affected by the acidic action (ISO, 1991; Penadille *et al*., 2006).

Conclusions

Emitter quality is vital to the precision, uniformity, duration, and resistance to clogging, which indicate the degree of reliability of irrigation equipment installed in a crop with specific conditions.

The difference in the emitter flow varied over time, depending on the emitter quality, installation, design, water quality, management, maintenance and use of the equipment.

The results showed that the advances that have been made in the fabrication of emitters, as seen in E2, have been favorable because E2 not only had the best performance but also decreased the costs of production, resulting in a continuous increase in its use for dripline irrigation.

The pressure-cleaning process in the laboratory with water did not work, while the cleaning with a solution of 5 g L^{-1} phosphoric acid presented a mean flow recovery in the emitters

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